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SPECTRALLY DERIVED INPUTS TO CROP YIELD MODELS

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ABSTRACT

Solar radiation as an energy source for plants is available only when it interacts with leaves. The ratio of total solar radiation intercepted (SRI) by a corn canopy has been described as a function of leaf area index (LAI) using Bouguer's Law, and is included in models which predict final corn grain yield. LAI for corn may vary greatly over large areas due to differences in planting dates, hybrids, stresses, and plant populations. Measurement of LAI is tedious and time consuming, which limits the use of models requiring LAI to relatively small areas. Spectrally-derived estimates of SRI may more accurately depict conditions in large crop production areas, and permit the application of crop models to large areas.

Agronomic and spectral data were collected in 1979 and 1980 at the Purdue University Agronomy Farm, West Lafayette, Indiana. Agronomic data acquired from several planting dates of corn (Zea mays L.) included LAI and final grain yield. Reflectance measurements were made in four wavelength bands using a Landsat band radiometer (Exotech 100A). In addition to the data collected at the Agronomy Farm, in 1978 Landsat MSS data were acquired for nine 5 x 6 n. mile segments with commercial corn fields in five states. Ten fields per segment were identified, and their spectral data analyzed. Crop development stages were monitored and final yield estimated for each of these fields.

Agronomic variables studied at the Purdue Agronomy Farm including LAI and calculated SRI were regressed on spectral data. In both years studied, SRI was better predicted than LAI, by the Greenness transformation. Spectrally estimated SRI, linearly interpolated and summed from planting to maturity was found to be positively correlated with final grain yield. Measured LAI, however, performed better in two crop yield models than spectrally predicted SRI.

The relationships developed from the data acquired at the Purdue Agronomy Farm were applied to the commercial corn fields using Landsat MSS data. In six of the nine cases examined, spectrally estimated SRI, summed from six weeks prior to six weeks post silking, was found to be positively correlated with final grain yield.

The use of spectrally estimated SRI alone to predict crop yields is not recommended. Spectrally estimated SRI used in conjunction with ancillary data, including meteorological data, is recommended in applications over large areas where it is not feasible to directly measure LAI.

I. INTRODUCTION

In recent years the world's food situation has emphasized the need for timely information on world-wide crop production. However, relatively few countries have reliable methods for gathering and reporting crop production information.

Remote sensing from aerospace platforms can provide information about crops and soils which could be useful to crop production forecasting systems. The feasibility of utilizing multispectral data from satellites to identify and measure crop area has been demonstrated (10). Relatively little research has been conducted on developing the capability of using multispectral data to provide information about crop condition and yield. Thus, if this spectral information can be combined effectively with crop models which depict limitations imposed on crop yields by weather and climate, then potentially much better information about crop yield and production can be gained.

Solar radiation as an energy source for plants is available only when it interacts with leaves. Considerable effort has been expended to estimate and measure the attenuation of light in crop canopies (12,6). The proportion of solar radiation intercepted by a corn canopy has been described as a function of leaf area index (LAI) (9) and is shown in Figure 1. This is an application of Bouguer's law using LAI of corn canopies and an extinction coefficient of 0.79 determined by Stevenson and Tanner (13). When LAI is 0, no energy is intercepted. When LAI is 2.8, about 90% of the visible solar radiation is intercepted by the canopy and is potentially useful to the crop.

In their work, Dale (2,9) and coworkers measured LAI and calculated the proportion of solar radiation intercepted (SRI) by corn canopies. They suggested a method to estimate an average LAI for corn canopies based on date of planting, accumulated thermal units and planting population (3). Corn LAI varies greatly over large areas, however, due to different planting dates, hybrids, stresses, and plant populations. LAI is tedious and time-consuming to measure accurately for small areas, difficult for fields, and nearly impossible for areas as large as a county. The use of yield models requiring LAI data is therefore limited to relatively small areas.

In a study of soybean (<u>Glycine max</u> L. Merr.) agronomic and spectral relationships, Kollenkark (8) found that the ratio of near infrared (0.8-1.1 μm) to red (0.6-0.7 μm) reflectance, and the greenness transformation (7,11) had more significant relationships with canopy characteristics including LAI and the percentage of soil covered by the canopy, than any single reflectance band.

Walburg (15) found that the near infrared to red ratio was a sensitive indicator of maize (<u>Zea mays</u> L.) LAI throughout the range of values examined.

The application of the above and other relationships of crop and spectral variables may allow the correlation of yield with remotely sensed and supplemental data over large areas, where it is impractical to directly measure crop canopy characteristics.

The overall objective of this study is to evaluate spectral data as a source of information for use in crop yield models. The specific objectives are (1) to identify important factors in determining yield that can be estimated from spectral data, (2) to evaluate those selected factors utilizing spectral and agronomic data acquired in controlled experiments at an agricultural experiment station, (3) to extend the factors that best estimate crop yield at the agricultural experiment station level to large areas using Landsat MSS data, and (4) to compare the results of estimating yield with and without spectral information.

II. MATERIALS AND METHODS

A. DATA BASES

Two sources of spectral data were used to assess the value of spectral information for predicting the yield of corn (Zea mays L.). Reflectance data acquired using a Landsat band radiometer (Exotech 100A) at the Purdue Agronomy Farm in 1979 and 1980 were used in initial testing and evaluation of the intercepted solar radiation (SRI) variable. These data provided detailed spectral and agronomic observations of approximately 50 plots in two years. The observations were collected at irregular intervals although all crop development stages are represented. Different cultural practices represented in these data included three plant populations , three planting dates, and two soil types (Table 1). Crop development stages (5) were noted throughout the growing season and grain yields were measured at harvest.

The other set of spectral data included Landsat MSS data acquired in 1978 over commercial corn fields in nine 5 x 6 nautical mile segments located in five states (Table 1). Within each segment up to 10 corn fields were identified and means and standard deviations were computed for each field in each spectral band for each date of a Landsat overpass. Crop development stages were observed at 18-day intervals from late June until harvest. Grain yield was estimated by each grower (farmer) at harvest.

B. ANALYSES

Leaf area index and the proportion of solar radiation intercepted by the corn canopy were described as functions of the near infrared to red (0.8 to 1.1 μm)/(0.6 to 0.7μm) reflectance ratio and the greenness transformation (greenness) using regression analysis. Previous research (8,15) has indicated that these two spectral variables are highly correlated with LAI and percent soil cover, and are relatively insensitive to soil mositure or soil color.

SRI predicted as a function of greenness was calculated for each day that spectral data were acquired and linearly interpolated for intermediate days throughout the growing season for each field. Two methods of accumulating the daily SRI values were examined. First, SRI was accumulated from the time the corn growing point emerged above the soil surface (6 to 8 leaf stage) to maturity. Second, SRI was accumulated from six weeks before to six weeks after silking.

The direct correlation between final yield and accumulated SRI was examined, as well as the inclusion of SRI in two crop yield models. The performance of spectrally estimated SRI was compared to measured LAI in two corn yield models.

Concepts and analysis techniques developed using data from the Purdue Agronomy Farm were extended to commercial fields with Landsat MSS data. Application of spectrally derived SRI to commercial fields requires the conversion of greenness values calculated from Landsat MSS data to greenness values calculated from the data collected using the Exotech Model 100A. Malila and Gleason (11) computed greenness transformation values for field reflectance measurements; however, data was unavailable for the direct comparison between Landsat MSS and Exotech Model 100A greenness values. An equation directly relating greenness values obtained from commercial fields (Landsat MSS) and the Purdue Agronomy Farm (Exotech Model 100A) was developed by correlating the seasonal variation between the two indicies (Figure 2).

III. RESULTS AND DISCUSSION

A. RELATION OF CANOPY REFLECTANCE TO LAI AND SRI

Results of the regression analysis of LAI and SIR as functions of spectral variables are shown in Table 2. For both

1979 and 1980 SRI was predicted better than LAI. Greenness predicted SRI better (larger R^2 value) than the near infrared to red ratio. Plant population, planting date, and soil type when included as terms in the regression model contributed very little additional information.

SRI predicted as a function of greenness will permit the results of the Purdue Agronomy Farm research to be extended to Landsat MSS data where only spectral data is available

B. RELATION OF SRI TO YIELD PURDUE AGRONOMY FARM

SRI values were estimated using spectral data for each day that spectral data were acquired and linearly interpolated for intermediate days. These daily values of SRI were accumulated from planting through maturity. This summed SRI represented the proportion of the total solar radiation available to the crop that was intercepted and potentially available for photosynthesis. The relationship between final grain yield and summed SRI is shown in Figure 3. Final grain yield was more highly correlated ($r = 0.72$) with summed SRI computed using the equation developed from the 1979 data.

One problem in crop response to light research is the confounding of solar radiation, temperature, and plant moisture stress effects on plant growth and yields. Dale (2) assumed that the reduction in crop growth was proportional to the reduction in evapotranspiration (ET) from potential evapotranspiration (PET). Coehlo and Dale (1) combined solar radiation, temperature, and moisture stress, with an SRI term in an Energy-Crop-Growth (ECG) variable (Figure 4) which was used to evaluate the daily effects of weather on corn growth and yield.

Three separate spectral variables were examined to determine their relationship to corn yields. First, maximum greenness which occurred at silking was used to represent the maximum LAI and vigor of the canopy. Second, SRI represented the integrated value of intercepted solar radiation during the critical period from 6 weeks before silking to 6 weeks after silking. Third, ECG combined both intercepted solar radiation and mositure stress for the 12 week period centered about silking. Each additional piece of information increased the correlation with yields (Figure 5) and indicated that together spectral and meteorological data can provide more information than either can alone.

While these correlations of spectrally-derived SRI with yield are encouraging, can this variable be substituted directly into existing corn yield models? To explore this issue, two corn yield models were selected which use an estimate of the proportion of solar radiation intercepted by the canopy. The Crop Growth Rate model (1) simulates crop growth and grain yield beginning when the corn growing point emerges above the soil surface (6 to 8 leaves) and ends at physiological maturity. The second model chosen was the Grain Growth Rate model (4) which simulates dry matter accumulation in the grain from silking to maturity.

For this initial test, a subset of six treatments representing three planting dates and 50,000 plants/ha from the two years was chosen. Grain yields predicted using SRI estimated from measured values of LAI were better correlated with observed yield than those using a spectrally derived SRI term (Table 3).

C. RELATION OF SRI TO YIELD COMMERCIAL CORN FIELDS

The second part of this study included the extension of the factors that best estimate crop yield and that are highly correlated with spectral data at the experimental plot level, to large areas using Landsat MSS data. Using equations developed from the experimental plots and Landsat MSS data, spectrally derived SRI was interpolated and summed from six weeks before to six weeks after the corn crop had silked. This cumulated SRI was regressed on the final grain yield observed on commercial corn fields in Landsat segments located in five states. Final grain yield was positively correlated with summed SRI in 6 of the 9 segments examined when the 1980 SRI-Greenness equation was used (Table 4). Three of the nine segments examined are contained in Figure 6.

One explanation for the poor correlations found in some Landsat segment cases examined is that greenness values may be high in situations where the crop may be subject to moisture stress. In this case, especially if the stress occurred at a critical stage of the crop's development (e.g. pollination) cumulative SRI may be high; however, yield can be drastically reduced. These results suggest the use of not only spectral, but also meteorological, data as input to crop yield models.

IV. SUMMARY AND CONCLUSIONS

Both LAI and SRI (calculated using Bouguer's law) were best estimated as a function of the greenness transform, as compared to a near infrared-red band ratio.

Spectrally derived SRI, interpolated and summed daily from the date of planting to maturity for six planting treatments over two years, was found to be positively correlated with observed final grain yield.

Spectrally predicted SRI, interpolated and summed from six weeks before to six after silking observed for commercial corn fields in five states was positively correlated with final yield in six of the nine Landsat MSS segments examined.

While two corn yield models performed better with SRI estimated from measured LAI, spectrally derived SRI must be used as inputs to models predicting yields for large areas as LAI measurement is tedious, time consuming, and requires a prohibitively large number of samples.

V. REFERENCES

1. Coelho, D.T. and R.F. Dale. 1980. An energy-crop growth variable and temperature function for predicting corn growth and development: Planting to silking. Agron. J. 72: 503-510.

2. Dale, R.F. 1977. An energy-crop growth variable for identifying weather effects upon maize yield. p. 240-248. In W. Baier, R.H. Shaw, L.M. Thompson, and R.E. Felch (ed.), Agrometeorology of the maize (corn) crop. Proc. Symp. Agrometeorol. Maize (corn) crop, World Meteorol. Organ., Iowa State Univ., Ames, Iowa, USA, 5-9 July 1976. WMO No. 481. Geneva, Switzerland.

3. Dale, R.F., D.T. Coelho, and K.P. Gallo. 1980. Prediction of daily green leaf area index for corn. Agron. J. 72:999-1005.

4. Gallo, K.P. 1981. An energy-crop growth variable - crop calendar model for prediction of corn grain growth and final yield. M.S. thesis. Purdue Univ., W. Lafayette, IN.

5. Hanway, J.J. 1963. Growth stages of corn (Zea mays, L.). Agron. J. 55:487-492.

6. Hatfield, J.L. and R.E. Carlson. 1977. Light quality distributions within three maize canopies. p. 232-239. In W. Baier, R.H. Shaw, L.M. Thompson, and R.E. Felch (eds.). Agrometeorology of the maize (corn) crop. Proc. Symp. Agrometeorol. Maize (corn) crop. World Meteorol. Organ., Iowa State Univ., Ames, Iowa, USA, 5-9 July 1976. WMO No. 481. Geneva, Switzerland.

7. Kauth, R.J. and G.S. Thomas. 1976. The tasselled cap--a graphic description of spectral-temporal development of agricultural crops as seen by Landsat. Proc. Symp. Machine Proc. Remotely Sensed Data. Purdue Univ., W. Lafayette, IN pp. 46-41-51.

8. Kollenkark, J.C., C.S.T. Daughtry, and M.E. Bauer. 1981. Influence of cultural practices on the reflectance characteristics of soybean canopies. Tech. Report 021781, LARS. Purdue University.

9. Linvill, D.E., R.F. Dale, and H.F. Hodges. 1978. Solar radiation weighting for weather and corn growth models. Agron. J. 70:257-263.

10. MacDonald, R.B. and F.G. Hall. 1980. Global crop forecasting. Science 208:670-679.

11. Malila, W.A. and J.M. Gleason. 1977. Investigations of spectral separability of small grains, early season wheat detection and multicrop inventory planning. ERIM Report 122700-34-F. Environmental Research Institute of Michigan, Ann Arbor, MI.

12. Norman, J.M. 1980. Interfacing leaf and canopy light interception models. pp. 49-67. In J.D. Hesketh and J.W.

Jones (eds.). Predicting Photosynthesis of Ecosystem Models. Volume 2. CRC Press.

13. Stevenson, K.R. and J.W. Tanner. 1970. Use of plastic plant models for investigating light distribution within a corn canopy. Can. J. Plant Sci. 50:319-329.

14. Stuff, R.G., and R.F. Dale, 1978. A soil moisture budget model accounting for shallow water table influences. Soil Sci. Soc. Am. J. 42:637-643.

15. Walburg, G., M.E. Bauer, and C.S.T. Daughtry,. 1981. Effects of nitrogen nutrition on the growth, yield and reflectance characteristics of corn canopies. Tech. Report 033181, LARS, Purdue Univ.

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Table 1. Experimental design and data acquisition for Purdue University Agronomy Farm plots and commercial fields.

<u>AGRONOMY FARM</u> - 1979, 1980

- SPLIT PLOT DESIGN
- CORN HYBRID Beck 65X
- TREATMENTS
  - 3 Planting Dates: 2, 16, 30 May 1979; 7, 16, 22 May 1980
  - 3 Plant Populations: 25,000, 50,000 and 75,000 plants/ha
  - 2 Soil Types: Chalmers (dark) and Fincastle (light)
  - 2 Replications
- AGRONOMIC DATA
  - Acquired at 5 to 10 Day Intervals
  - Included
    - Plant Height
    - Development Stage
    - Leaf Area Index
    - Percent Soil Cover
    - Fresh and Dry Biomass
    - Grain Yield
- SPECTRAL DATA
  - Acquired at 5 to 10 Day Intervals
  - Landsat Band Radiometer (Exotech Model 100A)

    0.5 to 0.6 μm
    0.6 to 0.7 μm
    0.7 to 0.8 μm
    0.8 to 1.1 μm

<u>COMMERCIAL FIELDS</u> - 1978

- LOCATED IN 5 STATES: IN, IL, IA, MO, SD
- AGRONOMIC DATA
  - Acquired at 18 Day Intervals
  - Included:
    - Development Stage
    - Plant Height
    - Grain Yield
  - Spectral Data
  - Acquired at 18 Day Intervals
  - Landsat MSS

    0.5 to 0.6 μm
    0.6 to 0.7 μm
    0.7 to 0.8 μm
    0.8 to 1.1 μm

Table 2. Results of regression analysis of agronomic variables on spectral variables for data acquired at the Purdue University Agronomy Farm.

Agronomic Variable = f(spectral variable(s))

Year (n)	Agronomic Variable	Spectral Variables	R^2	F
1979	LAI	green, $green^2$	.76	394.9
(255)	LAI	near IR/red	.77	843.0
	SRI	green, $green^2$	.90	1187.9
	SRI	near IR/red, $(near\ IR/red)^2$	.83	618.3
1980	LAI	$green^2$	.87	1367.5
(208)	LAI	near IR/red, $(near\ IR/red)^2$	.81	439.6
	SRI	green, $green^2$	.94	1659.0
	SRI	near IR/red, $(near\ IR/red)^2$	.92	1235.3

Table 3. Results of testing spectrally derived SRI and SRI calculated using measured LAI in two crop yield models for data obtained at the Purdue University Agronomy Farm.

MODEL 1 Crop Growth Rate[1]: Simulation began after emergence of corn growing point, ended at maturity.

RESULTS

Observed vs. predicted grain yield

Spectrally estimated SRI (1979 equ.)	r = -0.16
Measured LAI used to compute SRI	r = 0.90

MODEL 2 Grain Growth Rate[4]: Simulation began at silking, ended at maturity.

RESULTS

Observed vs. predicted grain yield

Spectrally estimated SRI (1979 equ.)	r = 0.42
Measured LAI used to compute SRI	r = 0.70

Table 4. Results of correlation of final grain yield from fields within Landsat MSS segments, and spectrally derived SRI (summed from six weeks before to six weeks after silking).

Landsat MSS Segment County, State	r value Observed Grain Yield vs. Summed SRI
Wapello, IA	0.55
Emmet, IA	0.25
Pottawattamie, IA	0.33
Ogle, IL	-0.59
Deuel, SD	0.51
Clark, MO	0.61
Henry, IN	-0.60
Benton, IN	0.24
Tippecanoe, IN	-0.32

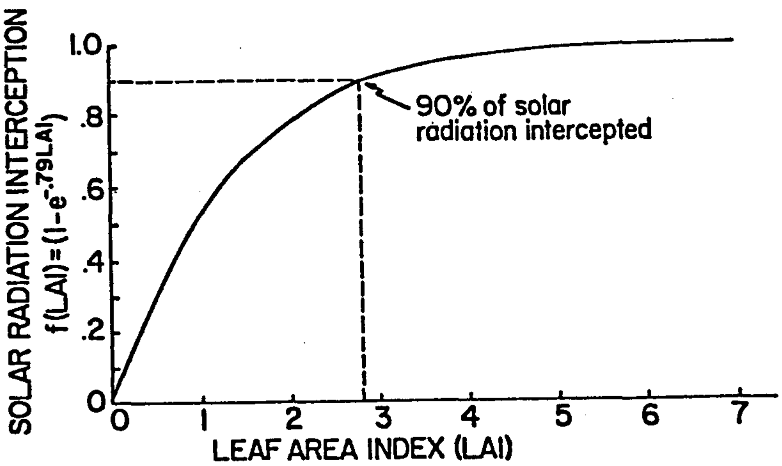

Figure 1. Solar radiation weighting factor for determining interception of solar energy by corn crop as a function of its leaf area index.

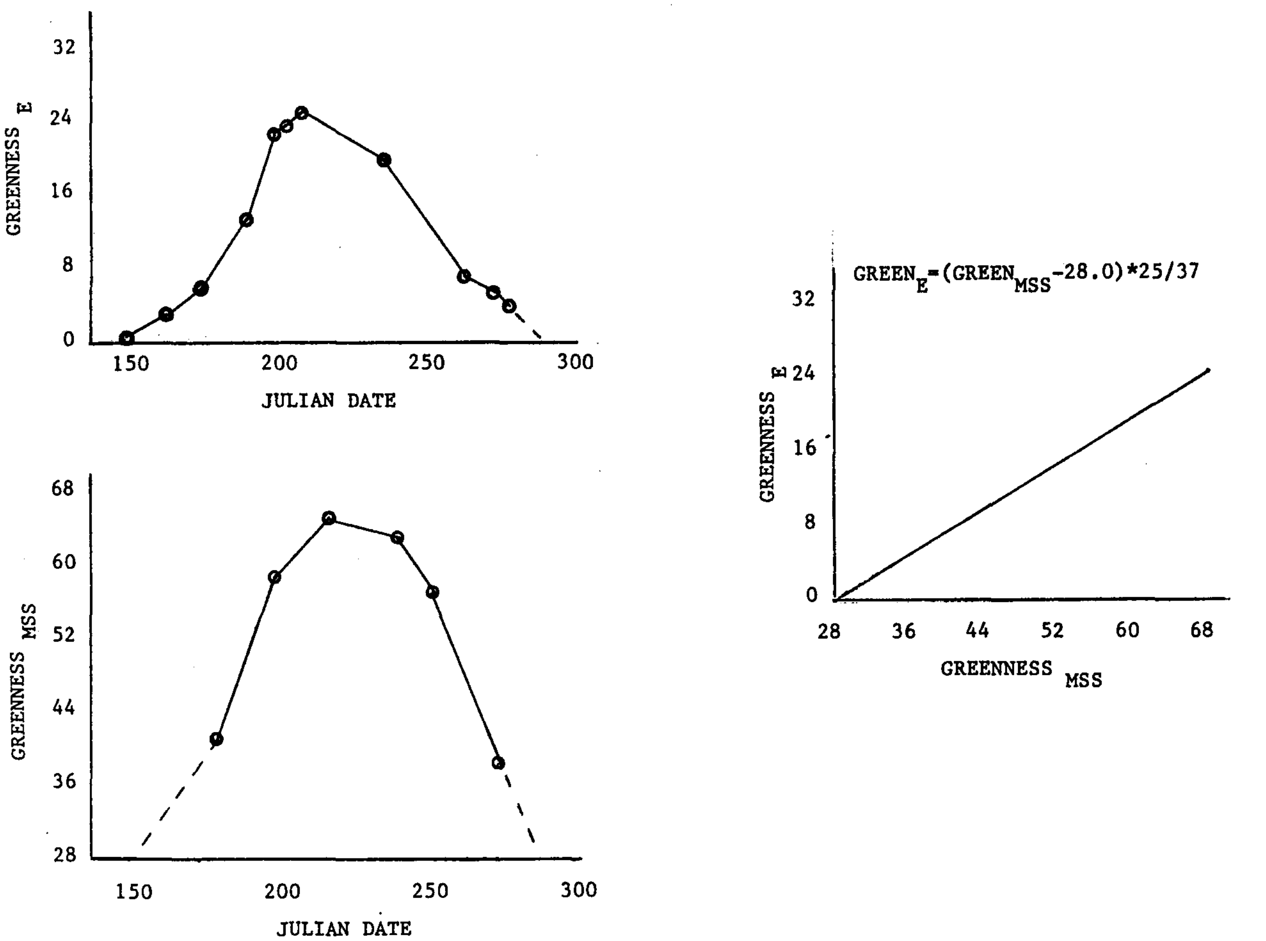

Figure 2. Seasonal variation between greenness values obtained from the Landsat MSS and Exotech Model 100A, and equation relating the two.

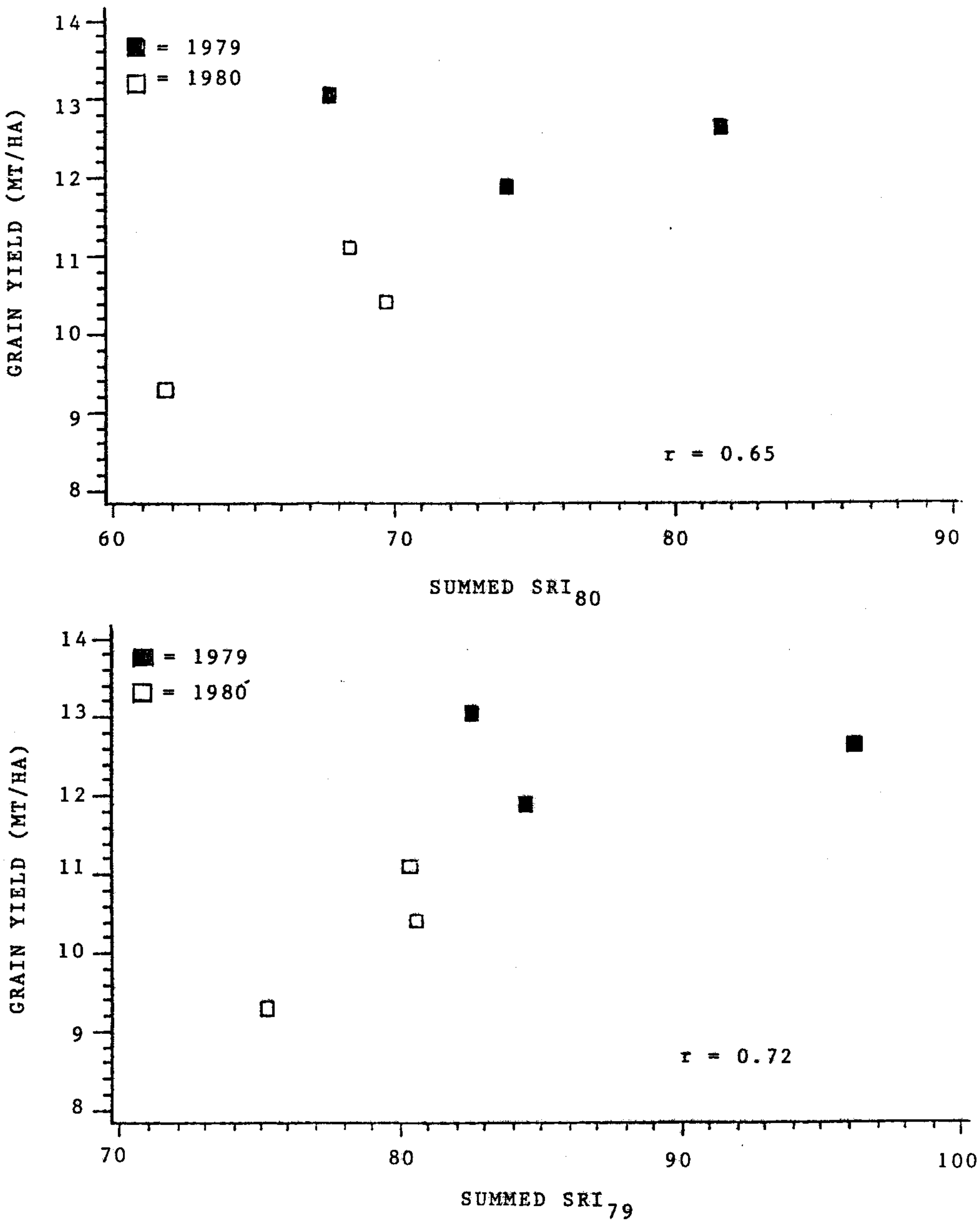

Figure 3. Relationship between final grain yield for six Purdue Agronomy Farm experimental plots and SRI. SRI was calculated with equations developed from data for both years interpolated and summed from planting to maturity.

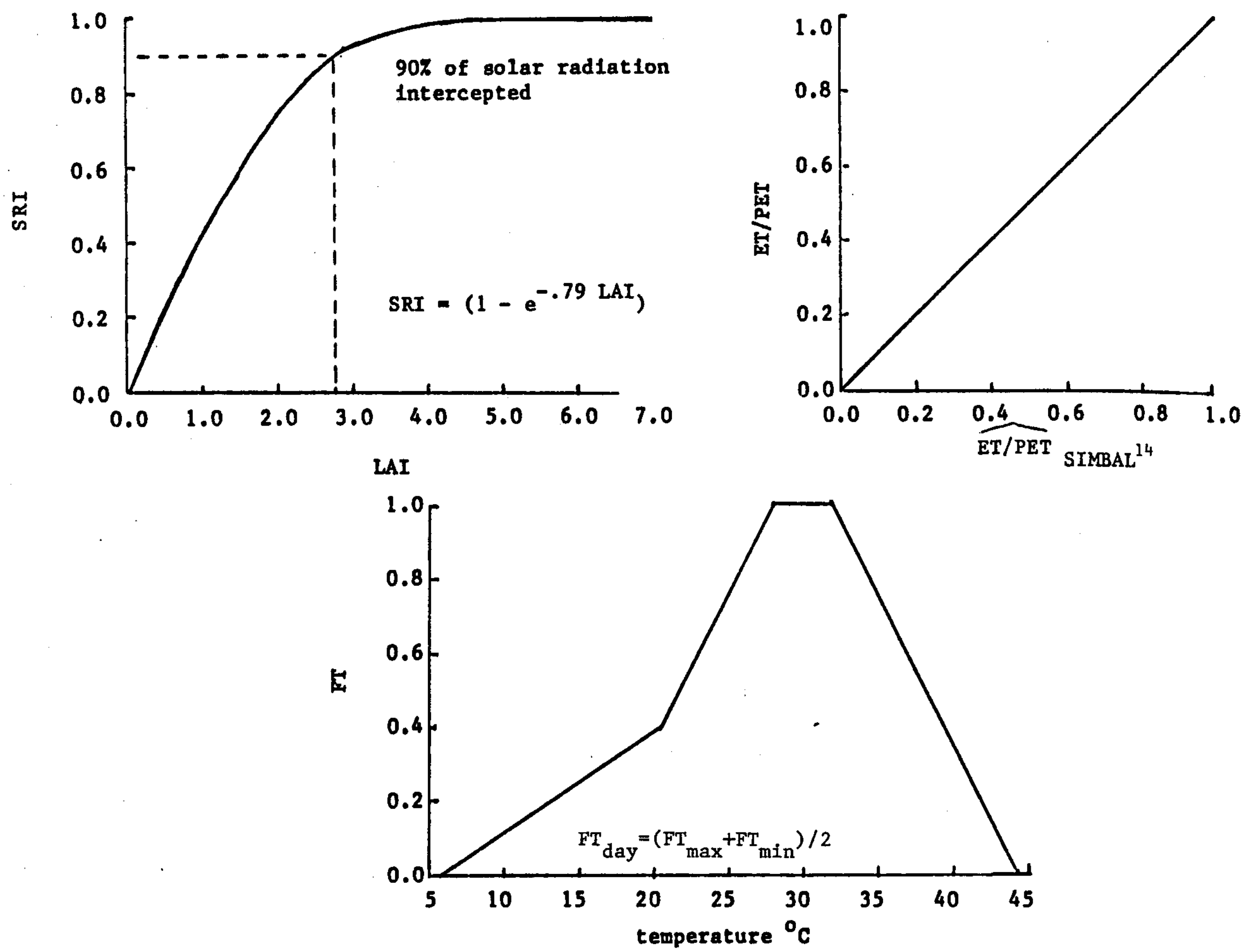

Figure 4. Factors comprising the Energy Crop Growth (ECG) variable, where ECG = (SR/600) * (SRI) * (ET/PET) * (FT).

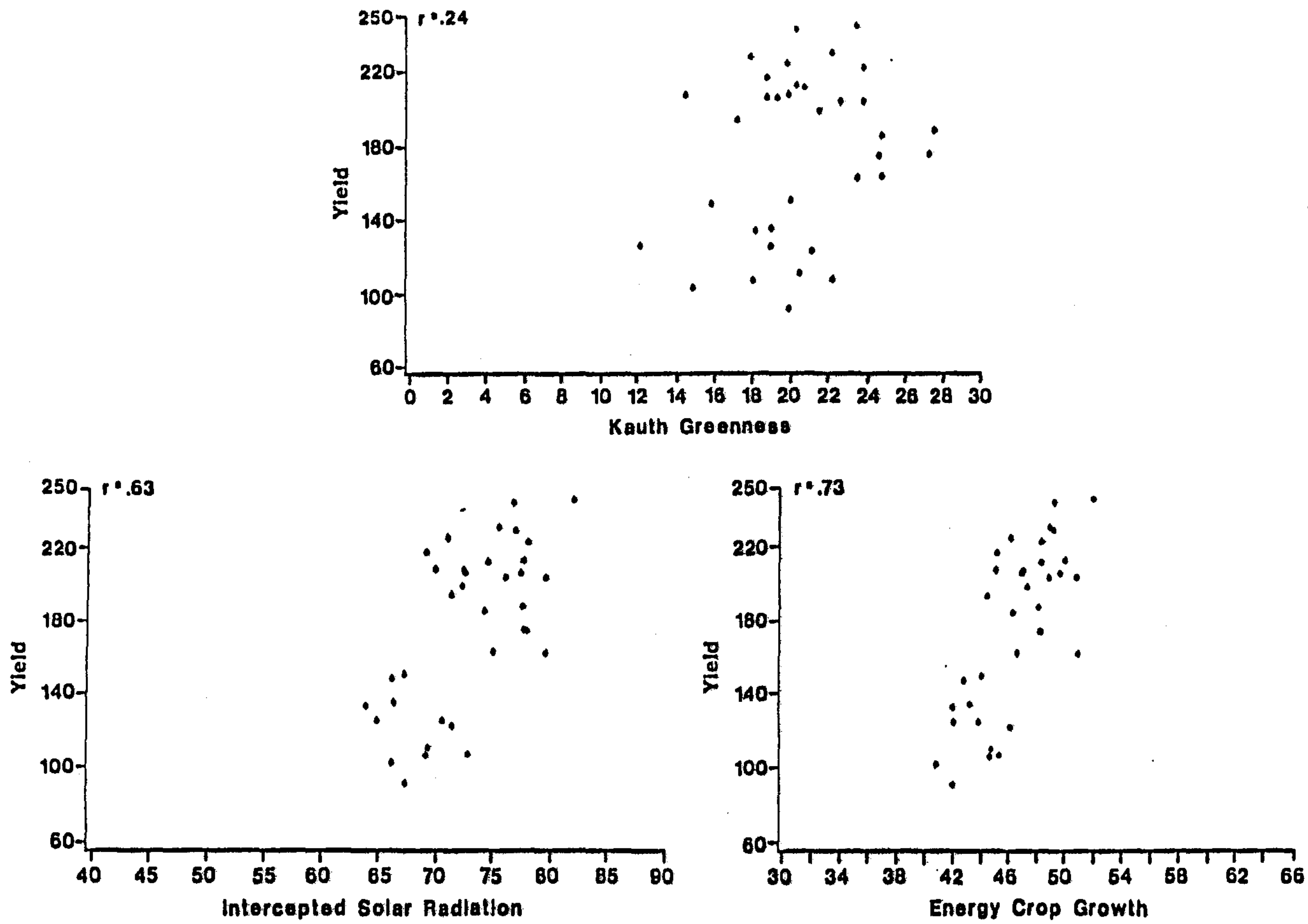

Figure 5. **Correlation of yield with three variables, each adding additional information to the prediction equation.**

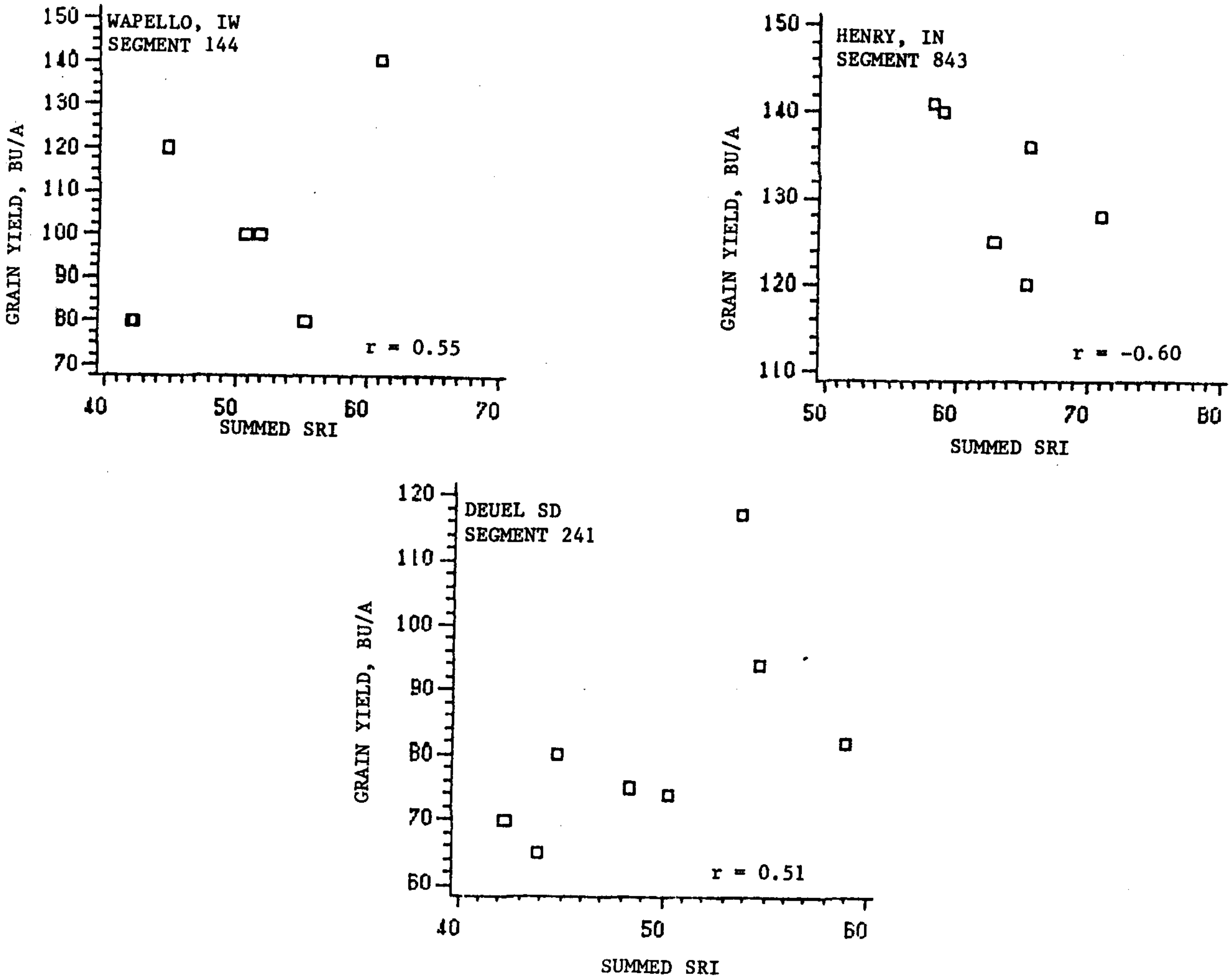

Figure 6. Relationship of final grain yield and spectrally derived SRI. SRI was interpolated and summed from six weeks before to six weeks after silking.